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AN EXPERIMENTAL STUDY OF FATIGUE IN THE AUDITORY MECHANISM

How long should a lecture be? Another question

By
FRANK A. PATTIE, JR.

F.C.

A DISSERTATION

PRESENTED TO THE FACULTY OF PRINCETON UNIVERSITY IN CANDIDACY
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY
ACCEPTED BY THE DEPARTMENT OF PSYCHOLOGY, MAY, 1925

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AN EXPERIMENTAL STUDY OF FATIGUE IN THE AUDITORY MECHANISM[1]

By FRANK A. PATTIE, JR., Harvard University

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It seems that in the past most physiologists and psychologists have assumed that the auditory mechanism is not subject to fatigue. No mention is made of such fatigue in any textbook of physiology or psychology known to the writer except Nagel's *Handbuch*. The work done on fatigue in audition has been meagre, with technique not above criticism, and often with negative or uncertain results. In fact, the failure of previous investigators to demonstrate the phenomenon with any certainty led Professor L. T. Troland, relying mainly upon the negative results of Sewall, to say in 1914 that "stimulation of the ear with a sound of constant intensity does not result in a decrease in the apparent intensity of the tone or noise, once the tensor tympani is adjusted, if the attention is unwavering."[2]

The work here reported was undertaken for the purpose of clearing up the uncertainty connected with the problem of fatigue in audition. The problem was to find out (1) whether there is a decrease in the intensity of a tone after the ear has been stimulated for a definite period of time, and (2) whether this decrease, if it occurs at all, is conditioned by psychological (especially attentional) factors and is only an apparent decrease, or is actually due to fatigue of a physiological nature.[3]

[1]From the Psychological Laboratories of Harvard and Princeton Universities. The writer takes this opportunity to express his thanks to Professors H. S. Langfeld, E. G. Boring, and M. J. Zigler for suggestions about this problem, and to the Scientific Equipment Division of the Western Electric Co. for the loan of apparatus.

[2]L. T. Troland, Adaptation and the chemical theory of sensory response, this JOURNAL 25, 1914, 500.

[3]The meanings of 'physiological' and 'psychological' as here used are illustrated by the names given to Hering's and Helmholtz's theories of simultaneous visual contrast; the former is very often called a physiological, the latter a psychological theory. The words are not meant to have any definite theoretical (*e.g.* dualistic) implication.

History of the Problem

There have been three lines of research on auditory fatigue; investigations have been reported on (1) the effect of prolonged stimulation of one ear upon the intensity of tones subsequently heard by it, (2) the effect of such monotic stimulation upon the localization of a subsequent diotic tone, and (3) the ultimate disappearance from consciousness of very high tones near the upper limen for pitch. This paper is concerned with the first of these methods of investigation.

A summary of casual and experimental observations (except for the work of Huijsman) prior to 1905 is given by K. L. Schaefer in Nagel's *Handbuch.*[4] Albrecht[5] summarizes all the work prior to 1919. It is therefore necessary to mention here only the more important experiments.

J. J. Müller[6] in 1871 reported that a clang sounded weaker and less rich if the ear had previously been stimulated by the frequencies corresponding to the overtones of the clang. The clang heard in an ear thus fatigued was compared with the same clang when heard in the unfatigued ear.

Urbantschitsch[7] in 1881 used tuning fork tones conveyed to the ears through rubber tubes. A tuning fork, after sounding before one of the tubes for 10 or 15 sec., was partially damped; and after its tone had died out completely it was removed to the open end of the tube leading to the other ear, whereupon the tone was regularly heard for several seconds by the unfatigued ear. The fatigue reduced in this way the intensity of tones, but only of those tones having the same frequency as the fatiguing stimulus. The duration of the fatigue-effect ranged from 2 to 5 sec.

In 1884 A. Huijsman,[8] of the laboratory of F. C. Donders, reported experiments designed to test the conclusions of Müller and Urbantschitsch. The latter's experiment was repeated with the added precautions of keeping the *Os*' heads steady by means of a biting board and fastening the fork in a block. With these conditions, the results were negative with 5 *Os*; without these conditions the results were "uncertain." Urbantschitsch had said that a fork tone loud enough to be heard by both ears was heard as louder by the unfatigued ear, but the *Os* could not be sure that this was the case. Huijsman, after a long account of experiments on the disappearance of high tones, reports experiments which do show fatigue to some extent, but apparently the two sets of experiments are not brought into relationship with each other. He conducted tones of 240 v. and 250 v. of equal intensity successively to the same ear. After stimulation by one of the tones for one or more minutes, the tones were compared, but the intensities were "little or not at all different." The apparatus was then modified so as to reduce the intensity of these tones until they were barely audible, whereupon "the difference remained slight, and where a difference was noticed it was due to a loss in the tone which had been used as a fatiguing stimulus." Forks of 210 and 250 v. were used, but with less convincing results, because of the difficulty of judging intensity where there was such a difference in pitch. In another experiment a 250 v. fork tone was led by a branching tube to the ears. After 2 minutes' stimulation of the left ear, the tone was heard stronger in the right ear when the tone was pre-

[4]K. L. Schaefer, in W. Nagel, *Handbuch der Physiologie des Menschen*, 3, 1905, 509-512.

[5]H. Albrecht, Zur Frage der physiologischen Ermüdbarkeit des Hörnerven, *Beiträge zur Anatomie* [etc.] *des Ohres* [etc.], 13, 1919, 202-229.

[6]J. J. Müller, Ueber die Tonempfindungen, *Ber. d. säche. Ges. d. Wiss., math.-phys. Kl.* 23, 1871, 115-124.

[7]V. Urbantschitsch, Zur Lehre von der Schallempfindung, *Arch. f. d. ges. Physiol.*, 24, 1881, 574-585.

[8]A. Huijsman, in *Onderzoekingen gedaan in het physiologisch laboratorium der Utrechtsche Hoogeschool*, 3de Reeks, 9, 1884, 87-142.

sented to the ears successively at low intensity. In several of these experiments no statement is made as to the number of *Os*.

The work of Sewall[9] was designed to give quantitative results. He planned to fatigue one ear with a given tone, then conduct the tone to both ears and have the *O* regulate the intensities so as to get equal loudness in the two ears. He hoped to use median localization in the head as a criterion of this intensive equality. The tones (from organ pipes and an electromagnetic siren) were conducted through telephones to the *Os*. The wires from the microphone near the source of sound ended in a primary coil, around which was a secondary coil, by adjustment of which the intensity of the tone received could be varied.

Preliminary tests showed that the adjustment of the sound intensities was very much modified, or at least rendered difficult, by the influence of suggestion. In order to eliminate this factor, the apparatus was so arranged that the position of the regulatory coils gave no clue to the relative intensities in the two ears.

Sewall stimulated one ear, say the left, for one or more minutes, and then the circuit to the right ear was also closed; whereupon *O* had to say in which ear the tone was louder (judging this indirectly from the localization within the head). In the first experiments the *O* regularly had the impression, as soon as the circuit on the right was closed, that the sound was very much louder on that side and that the source of sound was located in the right ear. *E* then sought to diminish the intensity on the right side so that the sounds would appear equally intense after the fatiguing stimulation, but such an enormous attenuation was required for the compensation of the 'fatigue' that Sewall came to doubt the previous interpretation of the phenomenon. The localization, moreover, did not change gradually from the unfatigued ear back to the median plane, but suddenly. These facts led Sewall to believe that the phenomenon was due to an attentional factor; the sound in the unfatigued ear sets in as something new, while in the 'fatigued' ear the tone simply continues as before. To test this hypothesis as to an attentional factor, he interrupted the tone in the 'fatigued' ear before allowing the two sounds to act diotically. An interruption of less than a second was sufficient to cause the 'fatigue' effect to vanish.

Albrecht[10] in 1919 reported a small number of experiments with himself and Dr. K. L. Schaefer as *Os*. A tuning fork was struck (c^2, c^4, and c^5 were used), and the average time during which it was audible was noted. Then a whistle of the same pitch was used as a fatiguing stimulus for one or more minutes, and immediately thereafter the fork was again struck and the duration of audibility again noted. This period of audibility was regularly shorter than it was when the ears were unfatigued.

J. C. Flügel[11] investigated the effect of fatigue on intensity by the use of tuning forks and rubber conducting tubes after the manner of Urbantschitsch but with some improvement on the method. In a series of experiments on 5 *Os* 40 trials were made on each ear, and in 46 % of the trials fatigue was shown. There were no marked differences between *Os* or between ears of the same *O* with respect to the degree or duration of the fatigue, which seemed to reach a maximum after stimulation for 40 sec.; a 3 min. period gave no increase in fatigue. No difference was found between the fatigue-effects of a loud sound and of a weak sound. The duration of fatigue was seldom more than 30 sec. In an experiment designed to test

[9]E. Sewall, Beitrag zur Lehre von der Ermüdung des Gehörorganes, *Zsch. f. Sinnes., physiol.*, 42, 1907, 115-123.

[10]Albrecht, *op. cit.*

[11]J. C. Flügel, On local fatigue in the auditory system, *Brit. J. Psychol.*, 11, 1920, 105-134, esp. 123-133. The greater part of this paper is concerned with the shift of localization produced by fatigue.

the effect of a fatiguing stimulus upon the loudness of tones of other pitches, all combinations of the forks 256, 320, and 512 v. were used. In all 214 judgments were taken, and in only 10 % of the judgments did the *O*s report that stimulation by one frequency caused a decrease in the intensity of other frequencies. Flügel regards this apparent decrease as due to errors of observation, since in about the same percentage of cases the opposite effect occurred (*i.e.* the sound was heard longer on the fatigued than on the unfatigued side). Further experiments with two *O*s showed that transfer of the fatigue-effect did not occur outside the range of their DLs for pitch.

The latest work is by Weinberg and Allen.[12] A tone from a Stern variator enclosed in a sound-proof box was interrupted periodically by a revolving disc and the slowest rate of interruption was found which still gave the impression of a continuous tone. The ears were then stimulated by another variator-tone for two minutes, and another reading was taken. The tones ranged from 140 to 250 v. The results indicated that "as a result of fatigue the persistency of sound impressions is greatly increased. The increase is a maximum when the frequency of the fatiguing tone is the same as that upon which the measurements are taken." The entire range affected was about 8 v. on each side of the maximum, and only a few tones very near the maximum were affected to any great extent. An idea of the order of magnitude of the effect may be had from the statement that fatigue reduced the length of the separate impulses of sound necessary for the impression of a continuous tone from about 0.020 sec. to about 0.018 sec. A decrease in the fatigue effect as the fatiguing tone increased in intensity "was clearly indicated," as was also an increase of fatigue with an increase of frequency. The authors interpret their results in terms of the resonance theory of audition.

The thesis of E. Sch fer[13] lies somewhat out of the range of this paper because of the phenomena he studied. His work is rendered of doubtful scientific value because he does not say whether he used more than one *O* (presumably himself). He investigated the fact that, if one sounds two tones, one from a tuning fork and the other from a monochord loud enough to mask the fork tone, and then damps the monochord tone suddenly, an interval of 0.01-0.15 sec. ensues in which the fork tone is not heard. The louder the monochord tone, the longer the silent interval. After becoming audible, the tone reaches a maximum loudness which exceeds the loudness it would have if heard without the preceding monochord tone, *i.e.* the subjective intensity runs beyond the objective intensity, as it were. These phenomena are explained as "more a psychological than a physiological process," since they are interpreted as due to cortical processes correlated with a shift of attention; and Sch fer gives an elaborate psychological explanation, adhering very closely to Wundtian theory.

He also investigated the fact that the length of time a struck tuning fork takes to become inaudible is increased if a fork of not very different pitch is sounded at the same time. The accompanying fork is damped at the moment when, on the average, the first fork (sounding singly) becomes just inaudible, and it is then found that the first fork is heard a few seconds longer than this average time. Sch fer gave a physical explanation of this phenomenon; he believed it to be due to a slight shift of the locus of excitation of the basilar membrane caused by the interaction of the two frequencies. This shift, too small to be appreciated as a pitch change, would allow the fiber that would have been stimulated by one of the tones sounding singly to "rest" and therefore to respond to the tone so as to give a sensation for a few seconds after the damping of the accompanying tone. Hence Sch fer thought that this work was an indirect attack on the prob-

[12]M. Weinberg and F. Allen, The effect of aural fatigue upon the critical frequency of pulsation of tones, *Phil. Mag.*, 47 (6th ser.), 1924, 126.

[13]E. Schäfer, *Ueber Ermüdung des Ohres*, 1911.

lem of fatigue. He was not able to duplicate the results of Urbantschitsch with the latter's method, but by closing the ears before a tuning fork was struck and afterwards opening them at the time when the fork tone would otherwise be just inaudible, he regularly heard the fork a few seconds longer.

To sum up critically, it may be said that doubt is cast upon the efficacy of Urbantschitsch's method by the work of Huijsman and Schäfer. The only quantitative data on the method are given by Flügel, who demonstrated fatigue in only 46 % of his trials, a percentage which shows that fatigue, as revealed by this procedure, is a labile phenomenon. The disadvantages of this method are that it involves, in at least some of its forms, reports on the presence or absence of liminal tones and that these difficult reports may be influenced by such factors as suggestion, confusion by other sounds, diversion of attention, etc. Sewall found in his experiment that suggestion was a strong influence.

The reason why Sewall was not able to demonstrate fatigue seems to be the fact that his measure of fatigue was unreliable. He tried to have the *O*s judge on the intensities of two tones presented simultaneously, one to each ear. The judgment of intensity was hence indirect, mediated by the localization of the resulting (fused) tone within the head. The adjustments of the apparatus to secure median localization, when both ears were unfatigued, were subject to considerable variation; and Sewall says in this connection, "Man sieht, dass die Genauigkeit binauraler Tonstärkevergleichung sich hier als eine sehr geringe herausstellt."[14] Undoubtedly it required a greater intensity-difference between the two ears to cause an appreciable shift in the localization of the acoustic image than that difference which was produced by one of the ears having been stimulated for two minutes.

We have in the work of Schäfer no direct proof that the ear is subject to fatigue, since his interpretation of his results as fatigue rests upon a very shaky theoretical structure.

Some references to articles not mentioned in this paper on account of lack of space are given in a footnote.[15]

Apparatus

The instrument used to produce tones was an audio-frequency oscillator with a range extending from 440 to 4500 cycles per sec. The tones were produced in the telephones of a radio headset, and the intensity of the tone in one telephone could be varied independently of the other tone by passing the current through a variable resistance. A circuit diagram of the oscillator is given in Fig. 1.

Rubber holders or cushions of annular shape, about 5 cm. in diam. and 3.5 cm. in depth, enclosed the telephones and held them against the ears, making a snug and practically sound-proof joining around them. The diaphragms were about 1 cm. further from the meatus than they would have been if the holders had not been used.

A difficulty was encountered at the beginning of the experiments, in that the telephones, even when disconnected from the oscillator, would give a weak tone (through induction) when the oscillator was operating nearby. This trouble was removed by short-circuiting the wires leading to the telephones by means of small relays. When absolute silence was wanted in a telephone, it was short-circuited; when the experimenter wished to,

[14] Sewall, *op. cit.*, 118.

[15] W. Köhler, Akustische Untersuchungen III und IV, *Zsch. f. Psychol.*, 64, 1913, 95 f.
F. C. Bartlett and H. Mark, A note on local fatigue in the auditory system, *Brit. J. Psychol.*, 13, 1922, 215-218.
R. Bleyl, Die funktionelle Ermüdung des Gehörorganes, *Arch. f. Ohren-, Nasen-, u. Kehlkopfheilkunde*, 108, 1921, 192-197.

make a tone in it, he closed a double-pole switch, which (1) connected the oscillator circuit with the wires leading to the telephone, and (2) closed a circuit through a relay, the effect of which was to break the short-circuit of that telephone. Small electric buzzers of the type used for the practice of radio signals were adapted for use as relays and attached to the backs of the telephones. The headset with these relays was rather heavy, but a counter-weight passing over a pulley was arranged to relieve the *Os* of the burden on their heads.

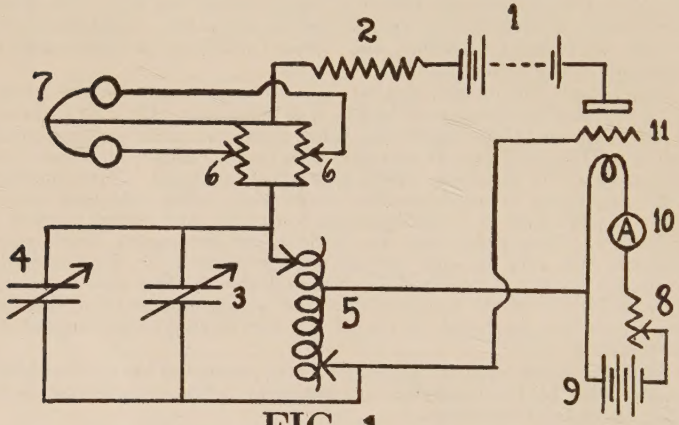

FIG. 1

FIG. 1. CIRCUIT DIAGRAM OF THE AUDIO-FREQUENCY OSCILLATOR. 1, 67 volt 'B' battery; 2, 5000 ohm resistance; 3, Dubilier step condenser, ten 0.001 mf. units; 4, General Radio Co. air condenser, 0.001 mf.; 5, tapped inductance, 3 lb. No. 30 D. C. C. wire; 6, 400 ohm potentiometer; 7, telephones; 8, 6 ohm filament rheostat; 9, 6 volt 'A' battery; 10, filament ammeter; 11, Western Electric Co. 216-A vacuum tube.

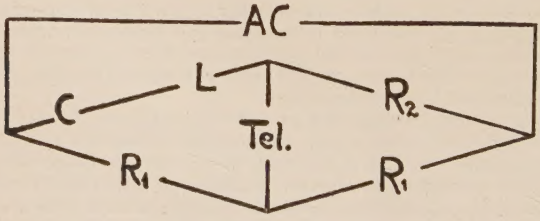

FIG. 2

FIG. 2. DIAGRAM OF AUDIO-FREQUENCY BRIDGE. The output of the oscillator is received at AC. C, capacity; L, inductance; R, resistance; Tel., telephone.

The oscillator was calibrated for frequency by means of an audio-frequency 'bridge' (Fig. 2) similar to the Wheatstone bridge for the measurement of resistance. This divided circuit, with constant capacity C and resistances R_1 and R_2 (the values of R and R_2 being chosen to balance with the resistance component of the LC circuit), but with variable inductance L, received the output of the oscillator of unknown frequency at AC, and the inductance L was then varied until the tone heard in the telephone was of minimum loudness. With this value of L the apparent resistance to the alternating current of the branch of the circuit containing C and L balanced R_2. The value of L was now read off and the frequency of oscillation found from a curve plotted from the formula $f = \frac{1}{2\pi\sqrt{LC}}$.

Since the tones of this oscillator were not pure, the need was felt for confirmation of the results with pure tones. The Scientific Equipment Division of the Western Electric Company very kindly loaned one of their 2-A Audiometers (which produce pure tones by means of electric oscillations) for this purpose. This instrument furnishes 8 tones at intervals of an octave, beginning with 64 and ending with 8192 v. These tones are approximately as pure as tuning-fork tones of the same intensity.

A further advantage of this instrument is that the intensity of the tones is accurately calibrated in terms of 'sensation units', *i.e.* when the energy of the tone is increased by one sensation unit the initial energy is multiplied by the Fechnerian ratio.[16]

Method of Investigation

The fatigue was investigated by means of a comparison of the intensities of a tone of constant energy[17] and frequency when heard (1) by a normal ear, and (2) by the same ear after being subjected to prolonged stimulation. This comparison was made by a method which may be described as follows:

Let E_l and E_r represent the left ear and the right ear, respectively. Two tones of the same pitch, symbolized by T_l and T_r, were used as stimuli for E_l and E_r, respectively. The two tones were presented successively, T_l always to E_l and T_r always to E_r, each for about one second, for comparison as to intensity. The energy of the tones was so arranged by the experimenter that in a small percentage of the cases the intensity of T_r was judged greater than that of T_l. Not less than 50 of these preliminary judgments were taken. The instructions given *O*, who was seated where he could not see the adjustments of the apparatus, were: "Compare the intensity of the tone heard in the left ear with that of the tone heard in the right ear, and report whether the intensity of the tone last heard is greater than, equal to, or less than that of the tone first heard." Other pairs of tones of the same pitch but of rather pronounced differences in intensity were interspersed among the T_l-T_r pairs, in order to keep *O* alert, but only the judgments on the T_l-T_r pairs were recorded.

After these judgments had been taken with both ears in a normal condition, E_l was stimulated by the fatiguing tone F_l (often T_l and F_l

[16]A more detailed definition is furnished by the handbook accompanying the Audiometer as follows: "When the dial is rotated, thus changing the voltage at the receiver terminals, the number of sensation units corresponding to this change is equal to 20 times the common logarithm of the voltage ratio. At any given pitch, the pressure on the ear is proportional to the voltage. The pressure on the ear is therefore changed by a ratio of 10 to 1 when the dial is rotated through 20 sensation units. The energy absorbed by the ear is changed by a ratio of 10 to 1 by rotating the dial through 10 units. The smallest steps are 5 sensation units, corresponding to a pressure ratio of 1 to 1.77 or an energy ratio of 3.16." (The pressure of a tone is directly proportional to the square root of its energy.)

[17]Hereafter in this paper the word 'intensity' refers only to sensation and not to stimulus, for which 'energy' is employed.

were the same) for 1 min. At the end of the minute F_l was cut off, and the tones T_l-T_r were given successively for comparison immediately thereafter and also at intervals of 10 sec. during a time ranging from 30 to 100 sec. after the cessation of F_l. After every pair *O* reported his judgment on the intensities of T_l and T_r, and the judgment was recorded by the experimenter. After F_l had been given once for the minute-period and the subsequent series of intensity-judgments taken, the experimenter then had recorded one judgment taken immediately upon the cessation of F_l, one judgment taken 10 sec. afterwards, one taken 20 sec. afterwards, and so on. The fatiguing tone was now given again and another series of judgments at 10-sec. intervals taken, and this process was repeated 15 or 20 times in the course of the sitting.

Since E_r was not subjected to any prolonged stimulation, it may be considered, for the purpose of this experiment, as unfatigued. Hence the intensity of T_r in E_r was treated as a constant element in the experiment and served as a standard against which the intensities of T_l (1) when E_l was fatigued and (2) when E_l was unfatigued were measured. The intensity of T_r was the middle term which allowed these two intensities of T_l to be compared and a fatigue effect was thus shown, if present, by a decrease in the intensity of T_l after prolonged stimulation of E_l.

This method may seem rather indirect, in that the fatigue is measured by the *O*'s reports indicating a relative increase in the intensity in E_r, the unfatigued ear, rather than by reports showing a decrease in intensity in E_l. The merit of the former procedure lies in the probability that it is less open to the influence of suggestion: if *O* were asked to r port on the intensity in E_l he might naturally expect it to be less after a minute's stimulation, and this expectation would be a complicating factor in his judgments; whereas, in order to gain an expectation of an incre se in the intensity in E_r, *O* would have to think over the experimental situation, a less likely possibility.

Variations of this fundamental method are discussed in a subsequent section.

The data obtained by this procedure may be presented either in tabular or in graphic form. The results of one experiment, in which the left ear of *C* was fatigued for 1 min. by a tone of 512 v. at an intensity obtained by setting the potentiometer dial[18] at 85, are shown in the graph in Fig. 3. The ordinate represents the percentage of judgments in which the intensity in the right ear was judged greater. The abscissa is marked off in units of 10 sec. and represents the time after the cessation of F_l. What the graph is designed to show is the percentage of judgments of 'greater intensity on the right' as a function of the time elapsed since the cessation of F_l. The dotted horizontal line which is drawn through the 18% line is called the 'normal line' and represents the percentage of judgments of 'greater on the right' which occurred when, at the beginning of the experimental hour, the *O* compared T_l and T_r under normal conditions 100 times. Each point plotted on the curve is derived from 20 judgments after stimulation of E_l. This particular curve is one of the smoothest obtained in this investigation.

The data upon which this curve is based are given in tabular form under Fig. 3. The same method of tabulation is used in Tables I to IV. The italicized numbers under the column heading 'Energy' represent sensation unit values on the audiometer; plain numbers represent readings on the potentiometer dial of the oscillator.

When the effect of a loud tone was to be compared with that of a weak tone, the loud tone was first used to stimulate the ear for 1 min., and a series of judgments was taken immediately afterward. Then the weak tone was used as a fatiguing stimulus for 1 min. and a similar series of

[18]Large numbers on the potentiometer dial of the oscillator corresponded to loud tones, and conversely.

judgments taken. The two tones were thus used alternately until the end of the experiment. The purpose of this alternation was to insure that any changes occurring in either *O*'s condition or the apparatus during the experimental hour would be reflected in both fatigue curves. The same method

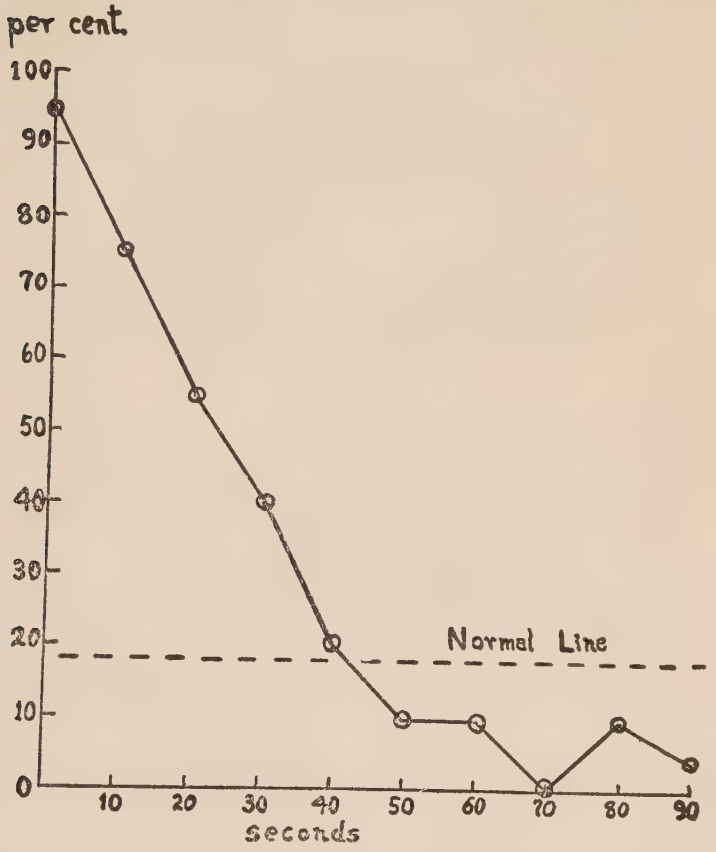

FIG. 3. GRAPH OF RECOVERY FROM FATIGUE, ILLUSTRATING THE RESULTS OF ONE EXPERIMENT. (See text.)

Tabulation:

		Fatiguing tone F						Percentage of judgments 'greater on unfatigued side' at									
O	Ear	pitch	energy	duration	T_1-T_2, pitch	Normal line at	No. judgments	0	10	20	30	40	50	60	70	80	90 sec.
C	L	512	85	1′	512	18	20	95	75	55	40	20	10	10	0	10	5

of alternation was used when the effect of increased duration of the fatiguing tone was tested and also when the influence of different pitches was investigated.

Observers

Thirteen *O*s were employed, 4 at Harvard in 1923-1924 and 9 at Princeton in 1924-1925.

The curve of fatigue shown in Fig. 3 represents the typical form of the curve which was eventually given by all *O*s except one. Every one of

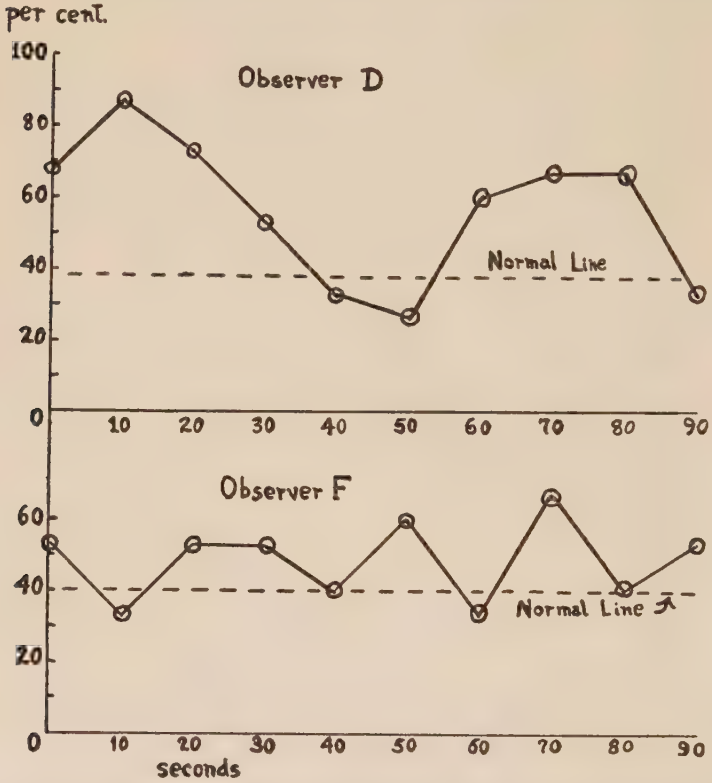

Fig. 4. Sample Curves of Observers *D* and *F*. Every point on the curves is determined by 15 judgments. *D* finally gave curves like the one in Fig. 3, while *F*'s curves continued to be as irregular as the one here shown.

the *O*s of the first group required considerable practice before his results on different days attained consistency among themselves and agreement with those of the other *O*s. The second group (at Princeton) did not require any practice; the curves given at the first hour they served were of the same kind as that in Fig. 3.

The *O*s of the first group were: *F*, *A*, graduate students, and *C* and *D* senior students. *F* and *C* were men; *A* and *D* were women. Every *O*

worked for about 15 weeks, coming once a week for an experimental period of two hours. *C* and *A* acted as *O*s for about 5 weeks before they began to give the usual form of curve. After they began to give this curve, they continued to do so the rest of the year. The results of the work with *F* and *D* were very irregular. Samples of curves given by them are shown in Fig. 4. Their results showed no consistency except that the curves were usually above the 'normal line.' These two *O*s were not discarded, how; ever, and finally, during the last two experimental periods of the year, *D* gave four curves of the usual form. *F* never gave a curve of the usual form- his remained like those in Fig. 4.

The members of the second group of *O*s were: *G*, professor; *B*, instructor; *K*, *L*, *M*, graduate students; and *H*, *J*, *E*, *I*, senior students—all of the Department of Psychology. These *O*s were employed for varying lengths of time and at rather irregular intervals.

Why the difference as to the need for practice existed between the two groups has never been clear. The apparatus and method, except for the addition of the audiometer in the second year, were the same in both years. With respect to *D*, it seems that the failure to obtain agreement with the other *O*s for so long a time might be due to her lack of interest in the experimental work, which she may have regarded merely as means of obtaining college credit. This explanation does not hold for other members of that group of *O*s, and no adequate explanation (in terms of conditions lying outside the *O*s themselves) has been found.

Results

The results of the experiments are recorded in Tables I to IV, inclusive. A study of the Tables yields the following facts concerning the fatigue-effect:

(1) *The degree of fatigue.* The maximum amount or degree of fatigue was found by subtracting the percentage of 'greater' judgments in the T_1-T_r comparisons before fatigue was established (represented in the tabulated data as the 'normal line') from the greatest percentage of 'greater' judgments which occurs after the cessation of the fatiguing tone. This method can be applied only to those series where the maximum percentage after fatigue is less than 100; for it is obvious that, once a sound is judged greater in 100% of the cases, its intensity may then be increased indefinitely and the percentage of 'greater' judgments will not reflect this change in intensity.

The subtraction mentioned was made in 53 series of results in Tables I, II, and III where the fatigue was produced by stimulation for 1 min. with a fairly loud tone (about 100 on the oscillator dial and 75-105 sensation units on the audiometer). The arithmetic mean of the increase in 'greater' judgments on the unfatigued side was found to be 57%; the median was 60%, with a mean deviation of 16%; *i.e.* the decrease in intensity of a tone due to fatigue under these conditions is, on the average, somewhat more than would be necessary to constitute a difference limen under usual conditions.

(2) *The duration of fatigue.* The method employed in these experiments will furnish only an approximate result with respect

TABLE I. THE NON-SPECIFICITY OF FATIGUE

In this and following Tables, L and R, under the column headed 'Ear,' stand for 'left' and 'right;' in other places, G, E, and L stand for 'greater,' 'equal,' and 'less,' respectively. Pitch is given in d.v. Where the oscillator was used, the numbers given under the column headed 'Energy' refer to readings on the potentiometer dial, and such readings for T_l and T_r are omitted because of the oscillator's lack of energy-calibration. Where the audiometer was used, the numbers under the 'Energy' column refer to sensation-units and are italicized. For further explanation of the method of tabulation, see the text referring to Fig. 3 and the tabulation under Fig. 3.

			F			T_l-T_r		Normal Line at	No. Judgments	Percentage of judgments 'greater on unfatigued side' at							
No.	*O*	Ear	Pitch	Energy	Duration	Pitch	Energy			0	5	10	20	30	40	50	60 sec
1	*A*	L	627	100	1′	512		20	15	100	—	67	20	0			
2	*B*	L	256	*85*	1′	2048	*70*	14	15	100	27	27	13	0	7		
3	*B*	R	256	*85*	1′	2048	*70*	8	15	60	53	47	20	7	7		
4	*B*	L	1024	*80*	1′	256	*70*	24	20	95	45	30	25	5			
5	*E*	L	512	100	1′	4500		20	15	73	67	47	53	27	13	13	
6	*E*	R	1024	*90*	1′	256	*55*	34	15	93	—	93	73	40	33	47	
7	*E*	L	512	100	1′	1330		34	16	94	69	81	69	69	31	13	
8	*E*	L	256	*85*	20″	2048	*50*	12	15	60	27	13	0	0			
9	*J*	L	512	100	1′	4500		10	15	93	87	73	53	33	40		
10	*J*	R	256	*85*	1′	1024	*70*	30	16	100	94	81	56	56	50		
11	*J*	L	1024	*95*	1′	2048	*80*	42	20	65	50	50	45	15			
12	*L*	R	4096	*80*	1′	256	*85*	38	15	87	93	73	47	40	40		
13	*M*	L	256	*65*	1′	1024	*70*	28	15	47	40	20	7	20	7		
14	*N*	L	512	100	1′	1330		22	15	100	100	100	87	67	60	40	27
15	*B*	L	512	100	1′	512		12	15	80	—	73	53	20	33	13	
			550							27	—	40	7	20	13	13	
16	*B*	L	512	100	1′	512		18	15	40	—	53	27	20	7	20	
			550							80	—	40	27	13	7	7	
17	*B*	L	512	100	1′	512		18	15	93	—	80	73	33	40	20	
			550							87	—	60	47	33	20	33	
18	*B*	L	512	*85*	1′	512	*70*	16	15	80	53	27	13	27	13		
			1024							67	53	27	20	13	7		
19	*C*	R	512	100	1′	512		20	15	93	—	80	33	0	0		
			627							100	—	93	13	0	0		
20	*C*	R	512	100	1′	512		38	15	100	—	80	53	0	0		
			627							33	—	0	0	0	0		
21	*C*	L	512	100	1′	512		13	15	100	—	60	0	0	0		
			627							93	—	60	13	0	0		
22	*C*	L	512	100	1′	512		14	15	100	—	80	87	47	0		
			1330							93	—	53	20	0	0		
23	*K*	L	512	100	1′	512		0	15	93	87	40	27	27	7	13	
			550							73	87	87	40	27	27	27	
24	*K*	L	512	100	1′	512		0	15	60	—	47	53	40	20	0	
			550							100	—	60	20	20	7	7	
25	*K*	R	256	*85*	1′	2048	*70*	0	15	40	33	27	27	20	20		

to the duration of fatigue, since one point on a fatigue curve (or one value in the series tabulated) is determined by only 15 or 20 judgments, and these judgments were taken at intervals of 10 sec.

The duration was measured by taking the time required, after the cessation of the fatiguing stimulus, for the fatigue curve to reach the 'normal line,' *i.e.* the recovery-time. This measurement was made in the series in Tables I, II, and III where the fatigue was produced by stimulation for 1 min. with a tone of

an energy equal to 75-105 sensation units on the audiometer (or a tone of 512 v. at intensity 100 on the oscillator).

The time of recovery in 51 series of this sort ranged from 10 to 60 sec. The median time was 33 sec.; the mean was 30 sec., with a mean deviation of 10 sec.

TABLE II. THE EFFECT OF THE ENERGY OF THE FATIGUING STIMULUS
(See legend of Table I)

No.	O	Ear	F Pitch	F Energy	F Duration	Tl-Tr Pitch	Tl-Tr Energy	Normal line at	No judgments	Percentage of judgments 'greater on unfatigued side' at 0	5	10	20	30	40	50	60	70 sec
1	*B*	L	512	100	1′	512		16	15	73	73	67	60	33	27	33		
				20						60	60	40	40	40	47	40		
2	*B*	L	512	90	1′	512		24	15	47	—	53	47	7	7	13		
				30						27	—	20	0	13	20	13		
3	*B*	L	512	100	1′	512		20	15	93	67	47	40	27	20	7		
				20						27	40	7	7	27	13	7		
4	*B*	L	1024	*90*	30″	1024	*75*	10	20	80	30	25	10	0				
				70						65	25	0	0	5				
5	*B*	L	1024	*95*	30″	1024	*70*	4	20	75	30	20	15	0				
				70						75	50	15	10	20				
				50						35	10	5	5	0				
6	*C*	L	512	100	1′	512		35	15	100	—	93	100	67	47	7	0	0
				20						33	—	40	20	20	7	0	7	0
7	*C*	L	512	100	1′	512		20	15	100	—	100	93	87	60	27	13	7
				20						73	—	80	47	27	13	0	0	0
8	*C*	L	1330	100	1′	512		14	15	93	—	53	20	0	0			
				20						33	—	27	7	13	0			
9	*C*	L	512	100	1′	512		36	15	100	—	93	93	87	67	27	7	0
				20						93	—	80	60	27	13	7	7	0
10	*D*	L	512	100	1′	512		10	15	67	—	40	20	7	7	27	7	27
				20						20	—	13	13	13	20	13	27	20
11	*I*	L	1024	*90*	30″	1024	*70*	*	15	G 67	53	27	7	— no 'less' judgments —				
				70						G 73	40	27	0	— only 2 'lesses' —				
				50					20	E 60	60	55	50	— no 'greater' judgments —				
12	*I*	L	512	100	1′	512		18	15	100	93	93	60	33	33	40		
				5						53	47	33	27	33	27	27		
13	*K*	L	512	100	1′	512		20	15	80	60	60	7	0	0	0		
				20						20	20	7	7	7	0	7		
14	*K*	L	1024	*105*	1′	1024		0	20	95	25	5	0	0				
				75						70	30	0	0	0				
15	*M*	L	512	100	1′	512		58	15	93	60	40	27	27	27	33		
				10						40	20	20	27	20	20	27		

* 36% 'equal,' 64% 'less.' Tl—Tr given in order left-right.

In 9 series in these Tables the 'normal line' was not reached within the 40- or 50-sec. limit of the series, and they were not considered in the above calculation on account of their indeterminateness.

Significant individual differences in the duration of fatigue do not appear. Twelve series of *B*, 12 of *C*, and 6 of *K* gave mean durations of 28, 34, and 33 sec. respectively. The mean deviations were 7, 10.5, and 11 sec., respectively.

(3) *The non-specificity of fatigue.* The results exhibited in Table I show, without exception, that fatigue produced by a

tone of a given frequency affects the intensity of all other tones used in the experiments. The tones used as fatiguing stimuli were 256, 512, 550, 627, 1024, 1330, and 4096 v. The comparison stimuli were 256, 512, 1024, 1330, 2048, and 4500 v. The series obtained when fatigue is produced by a tone of a pitch different from that of the comparison stimuli show, when plotted as curves, the same form as those curves obtained when fatiguing and comparison stimuli are of the same pitch.

Ten sets of results, Nos. 15 to 24, inclusive, embrace two lines of figures. These lines represent 2 series which were obtained in the same experimental hour for the purpose of comparing the degree of fatigue set up by a tone of 512 v. with that set up by some other tone. The comparison stimuli were in all cases 512 v. These data were all obtained by the method of alternation previously described.

In these 10 series, the effect of the other tone is approximately equal to that of 512 in 5 (17, 18, 19, 21, 23), less than that of 512 in 3 (15, 20, 22), and more than that of 512 in 2 (16, 24).

From these double sets of results and from the other series in Table I, the conclusion may be drawn that any of the tones used is as effective a cause of fatigue as any other one used in this investigation.

This finding does not cast any light upon a theory of hearing, since the seat of the fatigue is yet unknown.[19] The fact of non-specificity merely eliminates the statement, formerly accepted as a fact supporting the resonance theory, that the fatigue is confined to the pitch producing it.

(4) *The dependence of fatigue upon the energy of the stimulus.* In Table II 15 sets of results are given, wherein the effect of a loud sound is compared (in the same hour) with that of the same sound when diminished in energy.

Without exception these results show that less fatigue is produced by a weak tone than by a strong one, *i.e.* the fatigue is less and recovery from it is quicker.[20] A considerable difference in energy is required if a difference in fatigue-effect is to be shown, *e.g.* in Nos. 5 and 11 the tone 1024 v. produces the same result at 90 or 95 sensation units as it does at 70, but at 50 sensation units a markedly less effect is shown.

(5) *The dependence of fatigue upon the duration of the stimulus.* In Table III are gathered 18 sets of results in which the effect of increased duration of the fatiguing tone is tested. Here the results are not very clear cut. In 5 sets the effect of a 1-min. period is compared with that of a 2-min. period. In 4

[19]It is unlikely that the *tensor tympani* is concerned in the fatigue, since its reflex contraction is consensual. Cf. W. Köhler, *Zsch. f. Psychol.*, 54, 1909, 250.

[20]Nos. 1, 10, 11 and 12 form an exception to this last clause, since the values are very rregular at the ends of the series.

TABLE III. THE EFFECT OF THE DURATION OF THE FATIGUING STIMULUS

(See legend of Table I)

No.	O	Ear	F: Pitch	F: Energy	F: Duration	T_l-T_r: Pitch	T_l-T_r: Energy	Normal Line at	No. judgments	Percentage of judgments 'greater on unfatigued side' at 0	5	10	20	30	40	50	60	70	80	90
	A	L	512	100	2′ 1′	512		17	12	100	—	100	83	58	50	33	25	25	17	17sec.
2	A	L	512	100	2′ 1′	512		12	12	100	—	75	58	8	8	17	0	0	0	8
3	C	L	512	90	2′ 1′	512		21	15	100	—	100	75	58	50	50	25	17	17	17
4	C	L	512	100	2′ 1′	512		12	15	100	—	75	58	17	0	8	8	8	0	0
5	K	L	512	100	2′ 1′	512		14	15	93	—	87	73	60	47	7	0	0		
6	H	L	512	100	1′ 30″	512		7	15	73	—	67	27	7	0	0	0	0		
7	J	R	256	85	1′ 30″	1024	70	30	16	93	—	67	20	0	0	7	0	0		
8	L	L	512	100	1′ 30″	512		34	15	93	—	80	33	0	0	0	0	0		
9	B	R	256	85	1′ 20″	2048	70	8	15	87	—	80	47	27	20	7				
10	B	L	1024	80	1′ 20″	256	70	24	20	60	—	47	33	27	33	40				
11	B	L	1024	70	1′ 20″	1024	70	0*	15	87	67	47	13	7	0					
12	E	R	1024	90	1′ 20″	256	55	34	20	87	73	53	27	7	27					
13	E	L	256	85	1′ 20″	2048	50	12	15	100	93	81	56	56	50					
14	H	R	1024	85	1′ 20″	1024	75	0*	15	88	75	56	38	19	50					
15	I	L	1024	100	1′ 20″	1024	70	0*	15	100	87	73	67	47	67	40				
16	J	L	1024	95	1′ 20″	2048	80	42	20	100	87	80	73	80	67	73				
17	K	L	2048	80	1′ 20″	2048	80	0*	20	60	53	47	20	7	7					
18	L	R	2048	85	1′ 20″	256	70	88	15	60	67	73	7	13	7					
										95	45	30	25	5						
										85	50	35	15	20						
										73	40	20	0	20	* All equal.					
										87	80	20	7	0						
										70	70	55	30	25	35					
										50	55	40	25	25	20					
										47	33	27	7	0						
										60	27	13	0	0						
										L 60	33	27	13	0	* 12% less. No 'greaters' in the whole experiment. Comparison stimuli given in order left-right.					
										L 33	7	7	0	0						
										60	40	7	0	0	* 22% equal, 78% less. No 'lesses' given except in judgments before fatigue.					
										27	13	7	0	0						
										65	50	50	45	15						
										60	35	40	20	40						
										90	35	5	0	0	* All equal.					
										70	15	5	0	0						
										G 13	20	67	93	93	87	Comparison stimuli given in.				
										L 60	27	0	0	0	0	order left-right, right judged				
										G 27	53	87	87	80	87	in 88% of cases greater.				
										L 27	7	0	0	0	0	Right ear fatigued.				

instances stimulation for 2-min. gives a greater effect than for 1 min., while in the remaining series the effect of the shorter period is very slightly greater.

Of the 10 sets of series comparing the effects of 1-min. and 20-sec. stimulation, the longer period gives a greater effect in only 6 sets, in one set (No. 10) the effect is practically the same in both, and in Nos. 11, 13, and 9 (a very irregular curve) the 20-sec. stimulation gives more fatigue.

The remaining 3 sets of data deal with periods of 1 min. and of 30 sec. In Nos. 6 and 8 the effect is greater for the shorter period of stimulation, but longer stimulation gives greater fatigue in No. 7.

To summarize: the longer period gives the greater fatigue in 11 cases, less fatigue in 6, and no significant difference in 1 case.

If, however, we consider the results obtained immediately after the cessation of the fatiguing tone (entered in the column headed '0 sec.'), we find the shorter period producing the greater fatigue in only Nos. 11 and 13. The value under '0 sec.' is undoubtedly the most reliable point on the curves, since the *O*s said that the judgments then were easiest.

From the facts given above, it may be concluded that when periods of stimulation shorter than 2 min. are used, a period of 1 min. usually produces less fatigue than one of 2 min., and a period of 20 or 30 sec. usually produces less than one of 1 min.

(6) *An apparent sensitization-effect.* In Table IV are given 5 series from 3 *O*s which seem to indicate that occasionally a very weak tone, when used as a stimulus for 1 min., has an effect opposite to fatigue, *i.e.* its effect is to make subsequent tones of greater rather than of less intensity.

No. 1 in the Table shows in the first line the usual fatigue produced by a loud tone. The only judgments made in this part of the experiment were 'greater' and 'equal.' The next three lines show the judgments after the left ear had been stimulated with the same tone at a much lower level of energy. The result of the weak stimulation was to eliminate the 'greater' judgments entirely. The *O* (Professor Langfeld), well trained in such observation, reported 'less' and 'equal' only—never 'greater.' In the first members of the series, the 'less' judgments predominated, but they gradually diminished as time passed and gave way to increasing numbers of 'equals.'

No. 2 is of the same type as No. 1, but not so clear cut.

Nos. 3 and 4 are cases where the only effect of the weak tone was to depress the percentage of 'greater' judgments below the 'normal line' instead of raising it above in accordance with the usual effect. In No. 5, with the same *O*, 'less' judgments occurred for the first time in the experimental hour after the ear had been subjected to weak stimulation.

The writer is restrained, however, from concluding that the effect of weak stimulation is to sensitize the auditory mechanism, because his efforts to produce the sensitization-effect subsequent to its first appearance have in practically all cases failed. He has tried many times to produce the effect, but the result has been slight fatigue; the appearance of the sensitiza-

TABLE IV. AN APPARENT SENSITIZATION-EFFECT

(See legend of Table I)

No.	O	Ear	F: Pitch	F: Energy	F: Duration	Ti-Tr Pitch	Normal Line at	No. judgments		Percentage of judgments at 0	5	10	20	30	40	50	60	70 sec.	
1	G	L	512	100 20	1′	512	20	15	G	100	73	73	47	7	0	0		No lesses.'	
									G	0	0	0	0	0	0	0			
									L	93	80	73	13	20	0	7			
									E	7	20	27	87	80	100	93			
2	L	L	512	100	1′	512	42	15	G	93	60	47	53	60	47	53			
									L	0	7	20	7	27	20	20			
				20					E	7	33	33	40	13	33	27			
									G	13	13	20	27	53	73	47			
									L	60	33	20	20	0	13	7			
									E	27	54	60	53	47	14	47			
3	A	L	512	100 20	1′	512	60	15	G	100	—	93	67	13	7	7	0	0	No 'lesses.'
									G	7	—	0	7	0	0	0	0	0	
4	A	L	512	100 20	1′	512	26	15	G	100	—	100	93	73	33	27	13	7	—do.—
									G	0	—	0	0	7	0	7	0	7	
5	A	L	512	100 50	1′	512	16	13	G	61	—	13	0	0	0	0	0	0	No 'lesses.'
									L	62	—	46	31	15	31	46	46	46	No 'greaters.'

tion-effect has been on rare and unexpected occasions, when he was not trying to produce it. It is this feature of the effect which prevents him from drawing a conclusion, and not any suspicion of the actual data, which were obtained throughout by the method of alternation and with as much care as any of the other data in this paper.

Variations of the Fundamental Method

One of the objects of the investigation was to vary the conditions of the experiment in such a way as to insure, so far as possible, that the fatigue-phenomenon was of physiological, and not of psychological, nature.[21] As an example of a phenomenon of psychological origin, we may consider one of the facts reported by Sewall: if, after giving a fatiguing tone on the left side, he now threw in the tone on the right (without cutting off the left tone), the tone on the right seemed much more intense. He attributed this effect to an attentional factor; the tone on the right began as something new and changing, attracting attention to itself, and was therefore judged to be of greater intensity. The 'psychological' nature of the effect was shown by the fact that if he interrupted the fatiguing tone for one or two seconds before presenting the two tones simultaneously, the 'fatigue' effect vanished completely.

It might be objected that similar factors were at work in this experiment; after the fatiguing tone had been heard for a minute and was then cut off, the tone on the opposite side beginning immediately thereafter may, by virtue of its novelty, possess more clearness than the fatiguing tone. The relative durations of the tones may play a part also in conditioning judgments of intensity; the longer tone, being monotonous, may lose clearness. Of two tones differing only in clearness, the clearer might be judged the more intense, since (1) clearness and intensity are, to a certain extent, covariants and (2) the *O*s employed may not have been sufficiently trained to abstract from clearness in making their judgments.

The usual method of investigation was, therefore, varied in order to eliminate as far as possible any psychological influences which might be giving a false appearance of fatigue and in order to see if the fatigue-effect would disappear in other experimental settings.

The methods used were four:

(1) When F_l was the same tone as T_l the method was: E_l was stimulated with F_l. Simultaneously with the cutting off of F_l, without any appreciable interval, T_r was given in E_r. The *O* was instructed to compare the intensity of that part of F_l heard after the experimenter's ready-signal (given about 2 sec. before the end of F_l) with the intensity of T_r.

[21] Cf. footnote 3.

This procedure was used with *A*, *C*, *D*, and *F* whenever the fatiguing tone was the same as the comparison tone on the same side.

(2) This method was the same as (1) except that between F_l (=T_l) and T_r an interval of about 1 sec. intervened. This plan was followed in order to eliminate the shock, so to speak, of the very quick change from F_l in one ear to T_r in the other, a change which might be accompanied by an increase in clearness of the experience as the second tone comes suddenly into consciousness.

This method was used with *B*, *E*, *G*, *H*, *I*, *J*, *K*, *L*, *M* whenever F_l and T_l were the same.

(3) This method was employed when F_l and T_l were different in intensity or pitch or both. After F_l had been heard in E_l during the fatiguing period, it was cut off, and after 1 sec. T_l was given in E_l; then, after another pause of 1 sec., T_r was given in E_r.

This procedure was followed with all *O*s whenever the tones F_l and T_l were not the same.

In (2) and (3) both of the short tones T_l and T_r appeared as new stimuli with respect to the long fatiguing stimulus and were separated from each other and from the fatiguing stimulus by short intervals. It seems that, if clearness accrues to short sensations because of their novelty, then both T_l and T_r should receive equal increments. If there should be an unequal distribution of clearness due to the temporal order of the short tones, then the order should be changed to eliminate this factor. This change was made in Method 4.

(4) In this method, the usual order of presentation of T_l and T_r was reversed, and the stimuli were given in the order T_r-T_l. This method was used in the following series: Table I, Nos. 6 and 25; Table II, No. 13; Table III, Nos. 6 and 8; Table IV, No. 1.

It is apparent from an inspection of the series obtained by means of these different methods that the fatigue-effect appears in all of them and that no significant differences are shown by the results.

Since the first work with most of the *O*s consisted in obtaining the fatigue-effect when the fatiguing stimulus was of the same pitch as the comparison tones T_l and T_r, it might be objected that the *O*s acquired a 'set' or bias from this earlier work which led them to give the same results when the fatiguing tone and the comparison tones were of different pitches. This objection is met by Nos. 5 and 9 of Table I (transfer of fatigue produced by 512 v. to the intensity of tones of 4500 v.), which were obtained on the first occasion that each of these *O*s served.

The persistence of the fatigue-effect through all these changes of conditions affords ground for considering it to be of physiological not psychological nature. The facts, too, that there are no significant individual differences among the *O*s and that the results of any one *O* show consistency among themselves, afford further ground for believing that the phenomenon is conditioned by physiological changes caused by prolonged stimulation and is not due to a distortion of judgment produced by attentional factors, psychological contrast, or the like; for in the latter case a greater variability and instability of the fatigue-effect would not unreasonably be expected. Of course, no absolute proof of

the physiological nature of the effect can be given from the facts here set forth; the effect can only be shown to occur persistently in a variety of experimental settings.

Summary

(1) The result of prolonged stimulation of the auditory mechanism is a diminution of the intensity of the stimulating tone and of tones subsequently heard. This effect is called fatigue in this paper.

(2) This decrease in intensity amounts to somewhat more than one difference limen, when the stimulating tone is 1 min. in duration and of the energy corresponding to 75-100 sensation units of the Western Electric audiometer.

(3) The duration of this fatigue-effect is about 30 sec. under the conditions of paragraph (2) above.

(4) The fatigue is non-specific, *i.e.* the intensity of tones of pitch different from the stimulating tone is decreased by the latter.

(5) The degree of fatigue produced by a weak tone is less than that produced by a strong tone.

(6) The amount of fatigue produced by stimulation for 2 min. is usually more than that produced by stimulation for 1 min. Stimulation for 1 min. usually produces a greater amount of fatigue than stimulation for 20 or 30 sec.

(7) The fatigue-effect persists when the experimental setting is varied in such a way as to eliminate, so far as is possible, attentional or other 'psychological' factors.

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